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Project X: operation scenario update

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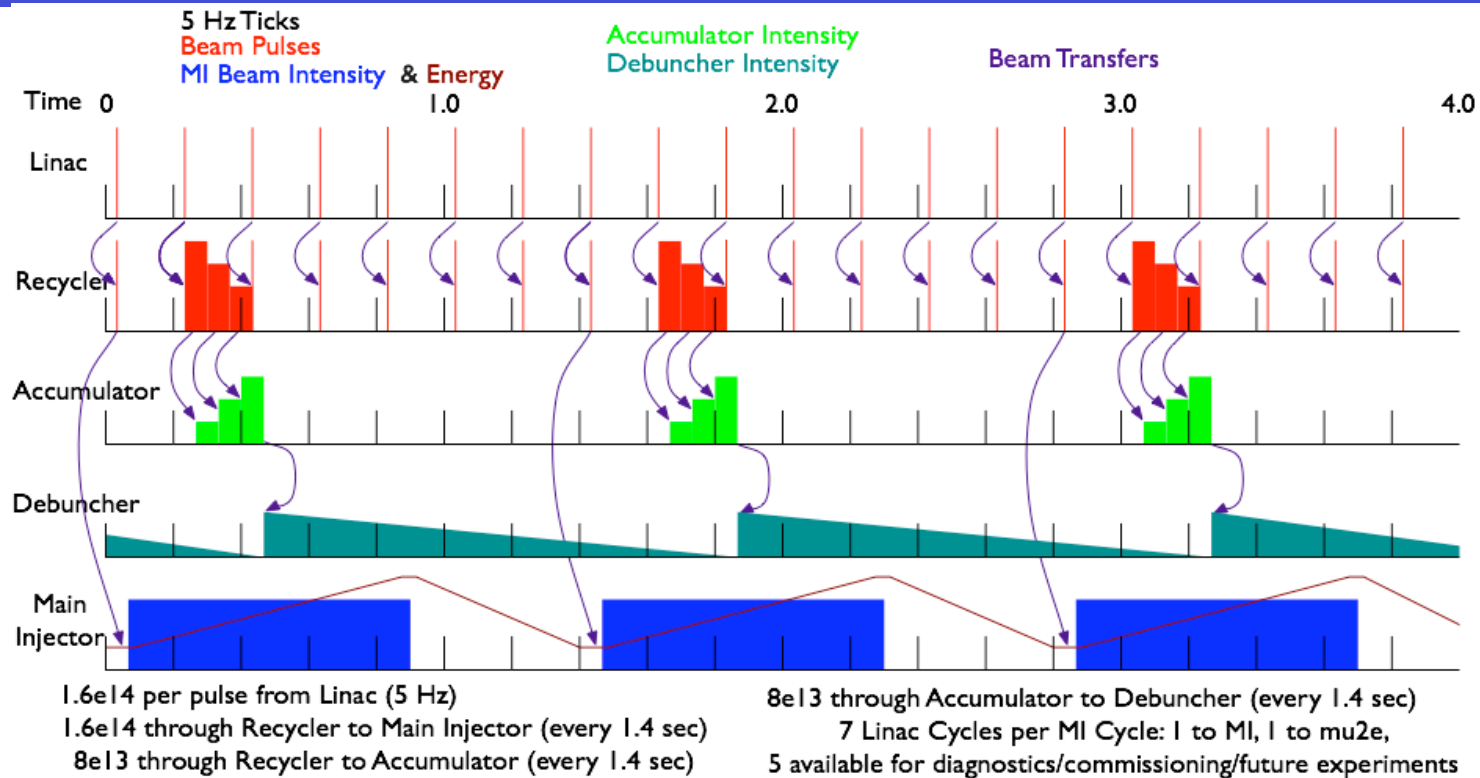
f Project X missions

- Neutrino program with MI: 2 MW at 60-120 GeV

- Mu2e program at 8 GeV: 150 kW slow spill

- Self-consistent upgrade path to muon collider

f What is wrong with operating scenario in ICD?

1. Five out of seven linac pulses are unused.
2. 8e13 every 1.4 sec to Mu2e does not work – (1) high tune shift in Debuncher, (2) long emittance too high (150 eV-s)
3. Incorrect linac chopping pattern to extract 3 batches from Recycler
4. Note: Mu2e beam power in this scenario is 75 kW

f New scenario: assumptions

- Recycler and Accumulator are available for rebunching
- Stripping injection in Recycler <u>only</u>
- Slow extraction from Debuncher <u>only</u>
  - ➢ Extraction cycle rate ~15 Hz (different from present Mu2e proposal)
- MI ramp cycles:
  - ➢ 1.4 sec for 120 GeV
  - ➢ 0.75 sec for 60 GeV

f Beam power requirements (8 GeV)

- 300 kW for MI at 60 GeV
  - ➤ 150 kW for MI at 120 GeV
- 150 kW for Mu2e
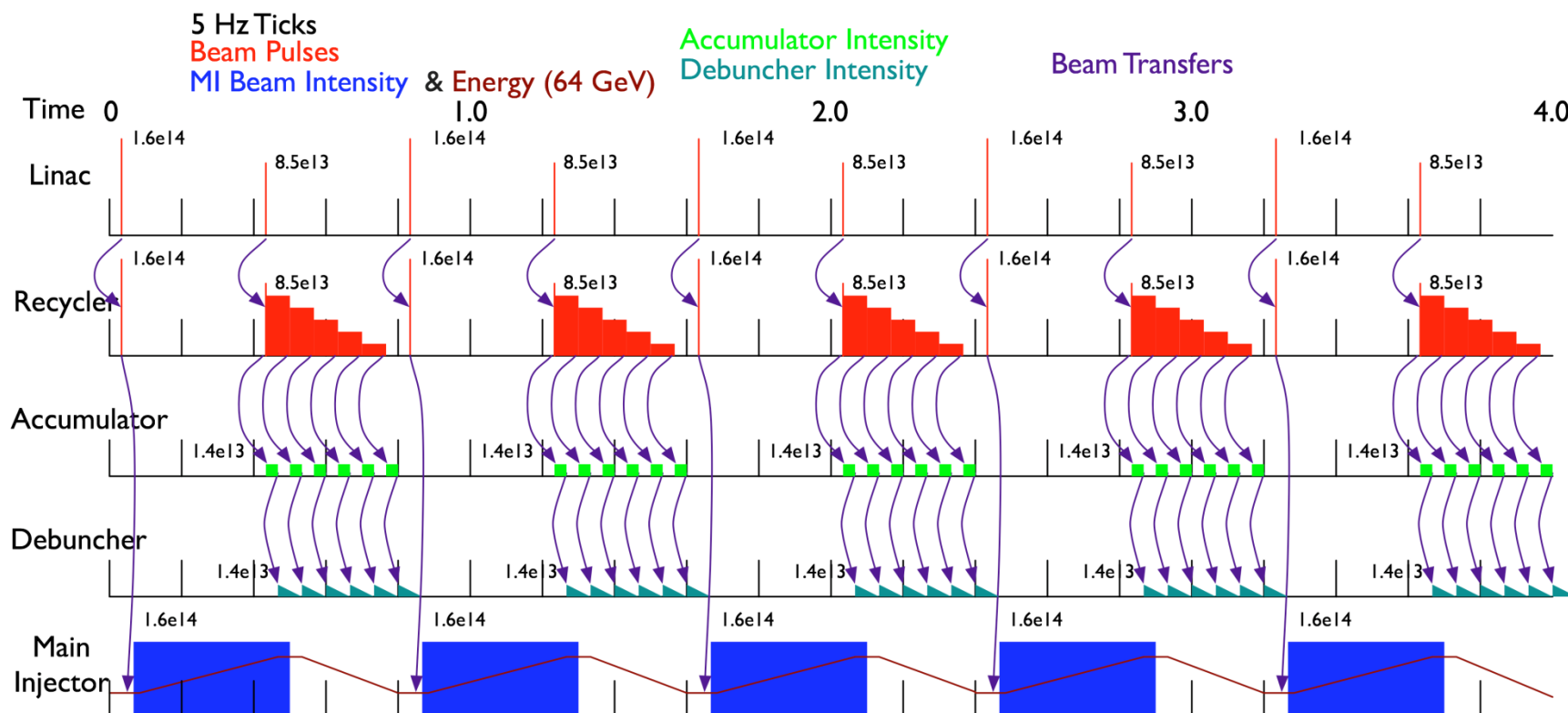 - ➤ 75kW possible with the present Linac+Booster at 15 Hz

- Total: 500 kW

Beam requirements at 8 GeV

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- **MI neutrino program:**
  - ➤ 1.6e14 protons every 0.75s
  - ➤ Beam quality unimportant
    - long and transverse painting to keep tune shift low (<0.1)
- **Mu2e**
  - ➤ Beam quality important (work back from the Debuncher)
  - ➤ 1.2e13 max per slow-spill cycle in the Debuncher
    - to keep tune shift <0.05 transv emittance (95%) should be 50 mm-mrad
  - ➤ Bunching pattern important (see following slides)
- **Muon collider**
  - ➤ At least 15 Hz, single bunch ~1-ns rms, 1 MW or more
  - ➤ Beam quality important
  - ➤ Bunching pattern important (see following slides)

New proposed scenario (MI@60 GeV)

5 Hz Ticks
Beam Pulses
MI Beam Intensity & Energy (64 GeV)
Accumulator Intensity
Debuncher Intensity
Beam Transfers

1.6e14 per pulse from Linac (2.5 Hz)
1.6e14 through Recycler to Main Injector (every 0.8 sec)
1.4e13 through Recycler to Accumulator (every 67 msec)

1.4e13 through Accumulator to Debuncher (every 67 msec)
2 Linac Cycles per MI Cycle: 1 to MI, 1 to mu2e,
2.12MW for neutrino, 136 kW to mu2e

Assumes 15 Hz transfers to Accumulator
Could use 17.5 Hz transfers (7 instead of 6 every 0.4 seconds)
159 kW to mu2e

f Mu2e beam requirements

- Working back from the Debuncher:
  - ➤ Single bunch: 25ns rms bunch length (100-160ns, FW)

Number of protons: $N := 1.2 \cdot 10^{13}$

Proton DC beam current: $I_p := N \cdot e \cdot f$ $I_p = 1.133\,A$

Normalized 95% emittance: $\varepsilon_n := 50 \cdot \mu m$ assume gaussian distribution

$$\Delta\nu := -\frac{3 \cdot N \cdot r_p}{2 \cdot \pi \cdot \beta \cdot \gamma^2 \cdot \varepsilon_n \cdot B} \qquad \Delta\nu = -0.053$$

  - ➤ To fit into Debuncher momentum aperture (±2%) the bunch momentum spread must be < 150 MeV (95%)
    - ~15-20 eV-s long. emitt (95%)
 - ➤ Must use Accumulator to prepare the bunch every 50 ms

f Single-particle simulations for Mu2e

- At t= 0 sec a batch of proton beam is transferred to Accumulator.
  - ➢ # of 53MHz bunches bunches ≤53, LE(95%) <0.2 eVs/bunch
  - ➢ Vrf(53MHz) = 30 kV
- From t=0-0.005 sec the bunches are partially debunched in the Accumulator
  - ➢ Vrf(53MHz): 30kV → 10 kV
- From t=0.005-0.015 sec a single bunch is formed in the Accumulator
  - ➢ Set Vrf(h=1)=10kV and Vrf(h=2)=2kV at t= 0.005sec
  - ➢ Turn off 53MHz rf system.
- At t= 0.015 sec transfer the single bunch from the Accumulator to the   Debuncher in h=4 rf bucket and start slow spill
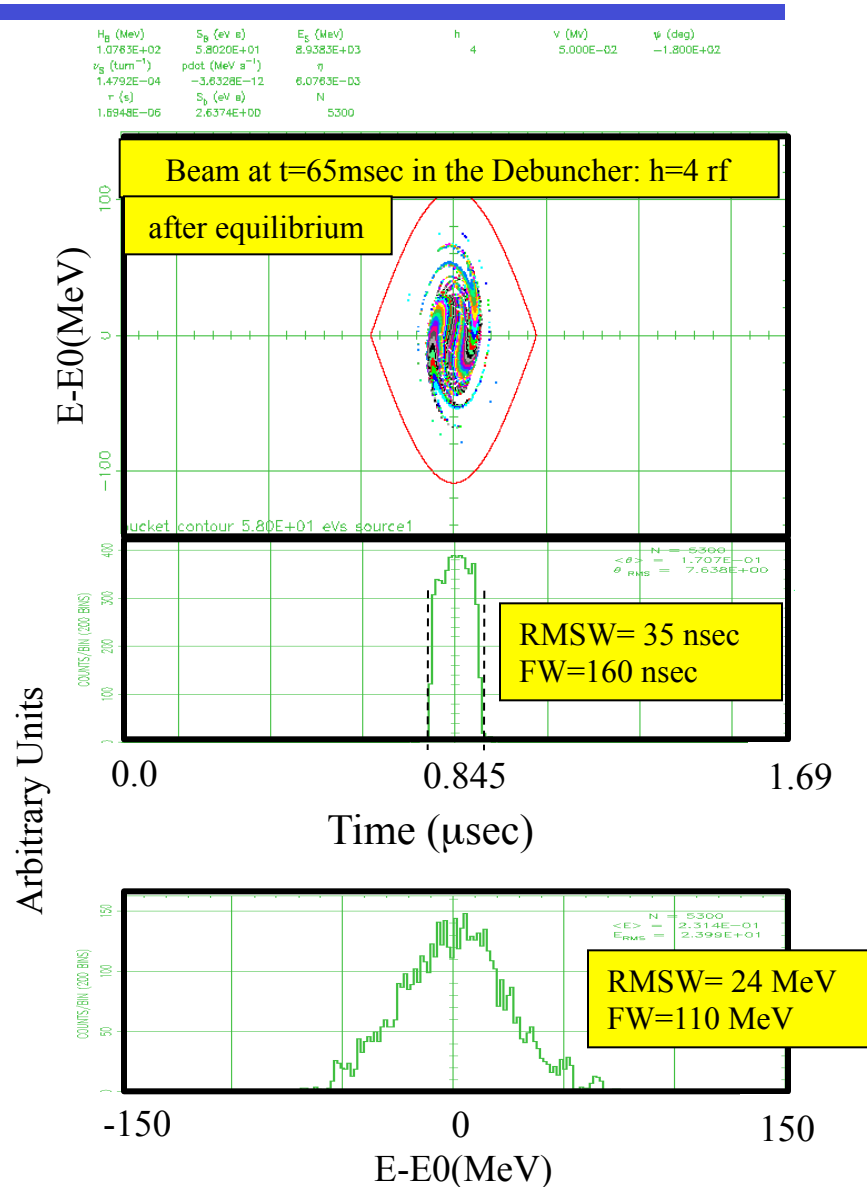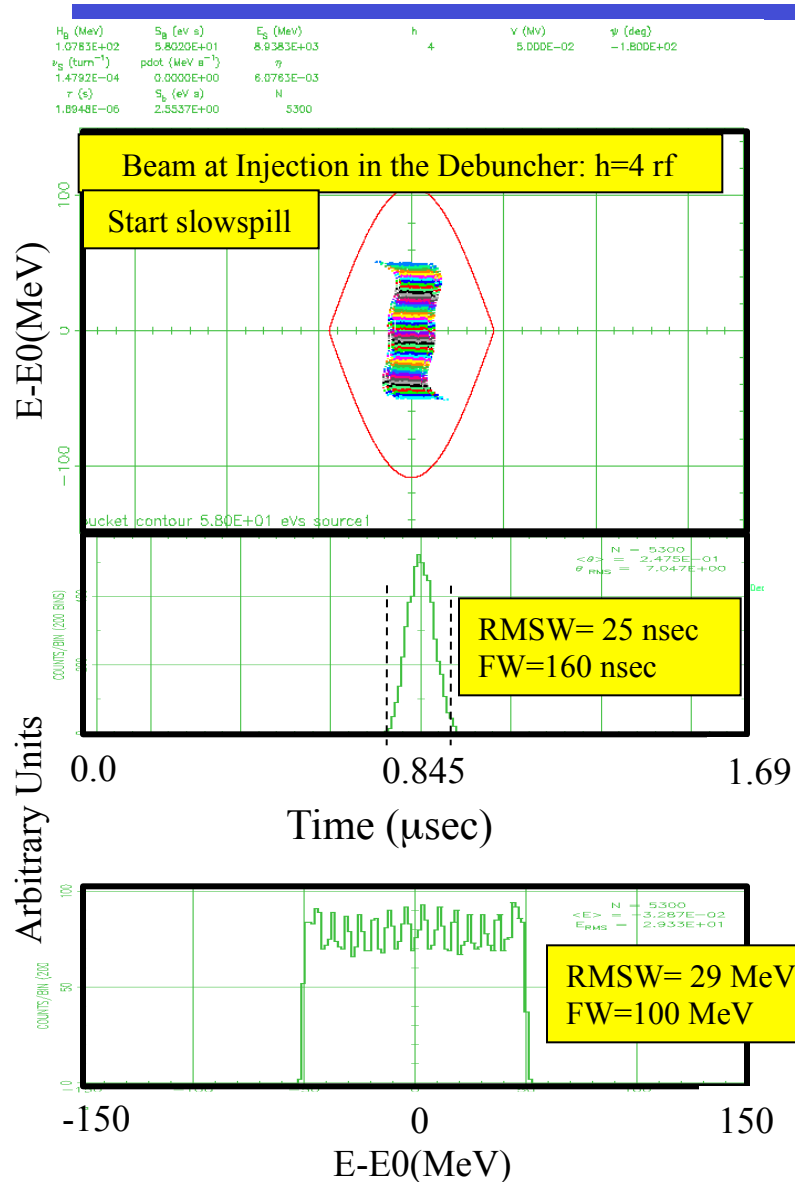 - ➢ Set Vrf(h=4)=50kV

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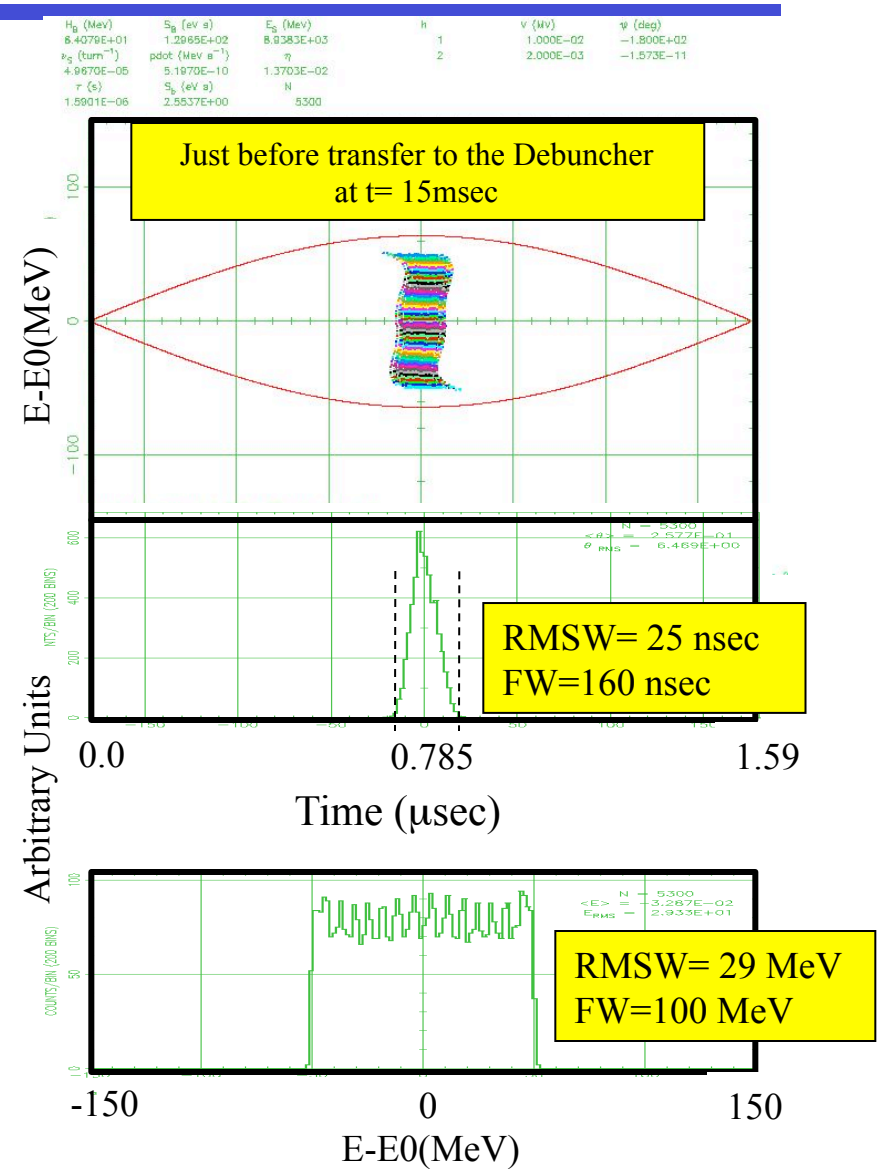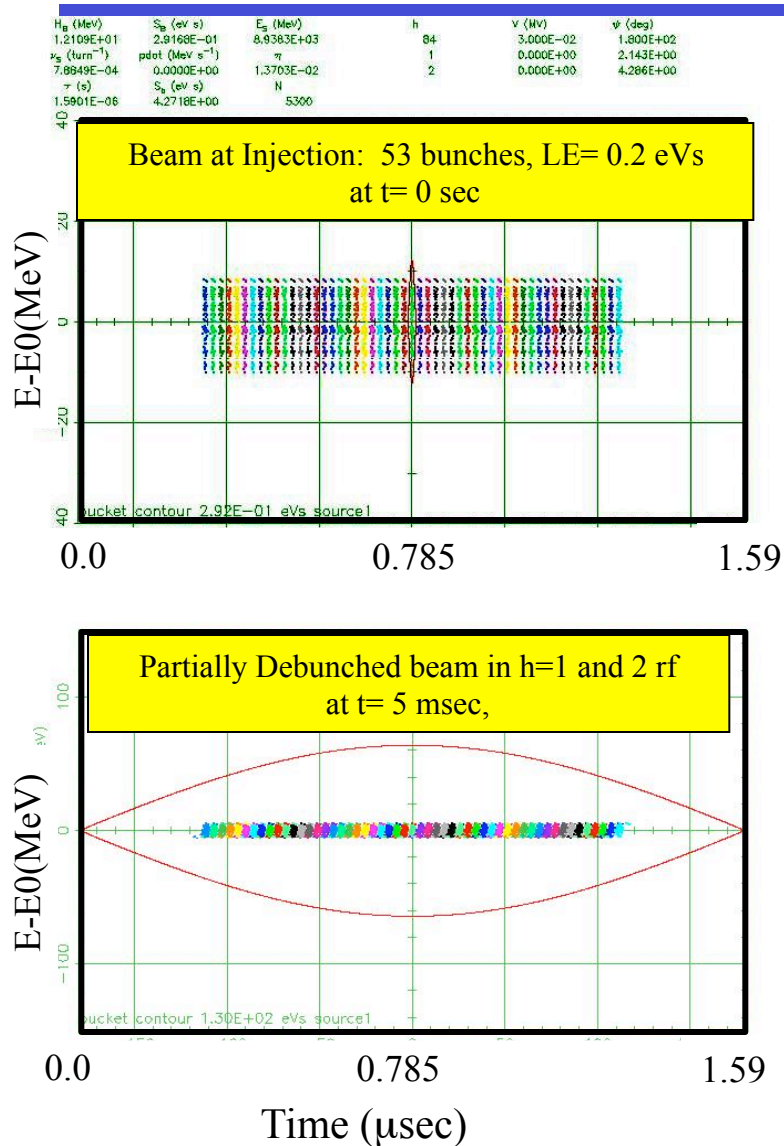
f   Summary for Me2e beam requirements

- A train of 53 bunches in the Accumulator can be rotated to form a 160-ns (FW) bunch with an acceptable momentum spread in <20 ms
  - ➢ Requires 0.2 eV-s (95%) per bunch (2.3e11)
  - ➢ However, ICD assumes 0.5 eV-s bunches (2.8e11)!!
- Required chopping pattern: 53 MHz + at 625 kHz: 31 empty bucket (0.6 μs), 53 with beam (1 μs).
  - ➢ Recycler is filled with 7 trains of 53 bunches each (31-bct gaps)
  - ➢ Each train contains 1.2e13 protons; 8.4e13 total
- RF requirements
  - ➢ Accumulator

RF System	Frf (MHz)	Vrf(Minimum)	Comments
h=84	53	30kV	15Hz rep rate
h=1	0.6289	10kV	15Hz rep rate
h=2	1.257	2kV	15Hz rep rate

  - ➢ Debuncher

RF System	Frf (MHz)	Vrf(Minimum)	Comments
h=4	2.36	50kV	15Hz rep rate

f Overall conclusions

- The total beam power requirement at 8 GeV can be reduced to 0.5 MW (from 1 MW in ICD) in the first stage (300 kW for MI, 150 kW for Mu2e)

- A scenario exists for a 2.5-Hz linac delivering 1.6e14 per pulse

  ➤ However, there is still a problem of insufficient long. phase-space density at injection in the Recycler to work with Mu2e at 15 Hz. May be solved if the slow-spill cycle is 30 Hz (14-15 trains in the Recycler) or by injecting in a barrier-bucket in the Recycler.

  ➤ MI and Mu2e (and muon collider) require different bunch chopping schemes. May need two choppers: (1) fast, to make 53 MHz bunches, (2) slow, to form bunch trains.

f   Proposed design criteria for Project X

1. Deliver 1.6e14 protons to MI every 0.8 s

    ➢ Beam parameters as in ICD

2. Deliver 150 kW beam (with specific long. emittance) at 8 GeV to Accumulator+Debuncher

    ➢ Mu2e must agree on a slow-spill cycle of 15 Hz or higher

    ➢ Must start simulations of slow extraction now (include space charge, chromaticity, losses)

    ➢ Note: ICD at present does not meet this criteria

3. Provide a plausible self-consistent path to a 1-MW (or higher) proton source for a muon collider

    ➢ single bunch, 1-2-ns rms, 15 Hz (or higher), 2mm rms spot size on target

4. Need flexible chopping patterns.